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Performance of forecasting, warning and detection of malaria epidemics in the highlands of western Kenya

Simon Hay¹, Melanie Renshaw², Sam A. Ochola³, Abdisalan M. Noor⁴, and Robert W. Snow⁴

¹Department of Zoology, University of Oxford, South Parks Road, Oxford, UK OX1 3PS

²United Nations Children's Fund (UNICEF), Eastern and Southern African Regional Office, UN Complex Gigiri, P.O. Box 44145, Nairobi 00100, Kenya

³Division of Malaria Control, Ministry of Health, P.O. Box 20750, Nairobi, Kenya

⁴Kenya Medical Research Institute/Wellcome Trust Collaborative Programme, P.O. Box 43640, 00100 Nairobi GPO, Kenya

Abstract

On the 4th July 2002 a leading national newspaper in Kenya, the *Daily Nation*, ran the headline 'Minister sounds alert on malaria' in an article declaring the onset of epidemics in the highlands of western Kenya. There followed frequent media coverage with quotes from district leaders on the numbers of deaths, and editorials on the failure of the national malaria control strategy. The Ministry of Health made immediate and radical changes to national policy on treatment costs in the highlands by suspending cost-sharing. Development partners and non-governmental organisations also responded with a large increase in the distribution of commodities (approximately US\$ 500 000) to support preventative strategies across the western highland region. What was conspicuous by its absence was any obvious effort to predict the epidemics in advance of press coverage.

One of the strategic pillars of the Roll Back Malaria (RBM) movement's efforts to reduce the burden of malaria in Africa is the application of malaria early warning systems (MEWS) to facilitate timely responses to prevent and contain epidemics [1–3]. A joint United Nations Children's Fund (UNICEF) and Division of Malaria Control (DoMC) team was sent to assess the true extent of the media publicised emergency. A full report of the findings and recommendations is available [4], as well as a brief policy summary [5]. Here, we retrospectively examine meteorological and disease data for the western Kenyan highlands to determine what contribution seasonal climate forecasting, early warning and early detection may have made to preparedness activities in early 2002.

The western highlands

The highlands of Kenya are located in the southwest of the country and bisected by the Rift Valley [6] (Fig. 1). Malaria first appeared in the western highlands of Kenya in the 1920s with the influx of gametocyte-laden labourers and their creation of breeding sites during railway construction [7]. Malaria epidemics were frequently reported in the 1930s and this continued until widespread control efforts during the 1950s and 1960s including the residual spraying of DDT, chemoprophylaxis and mass drug administration [8–10]. The effective,

widely available and affordable antimalarial chloroquine (CQ) helped to keep transmission low throughout the 1970s [11]. The recrudescence of seasonal outbreaks of malaria since the late 1980s is thought to be related to the widespread emergence of CQ resistance in Kenya [12], coupled to a decrease in efficacy of vector control and clinical services [13]. Today, the highlands of western Kenya are best described as mesoendemic (low, annual risks of parasite exposure among the human population) with marked seasonal increases [14] whose magnitude is subject to significant inter-annual variation.

Malaria early warning systems

A MEWS is a series of approaches that refine our understanding of the geographical variation malaria risk [15,16] in a dynamic environment [17] and usually comprises forecasting, early warning and early detection [2,18]. In this context, forecasting refers to seasonal climate forecasts, early warning refers to the monitoring of meteorological conditions and early detection is case surveillance [3].

Seasonal climate forecasting

An increase in the capacity to model weather systems [19,20] and the perceived success of seasonal climate forecasts (SCF; predicting climate 3–6 months in advance) during the 1997–1998 El Niño [21] brought the potential of SCFs to the attention of the malaria control community [2,22]. The Greater Horn of Africa Climate Forum (GHARCOF) published in February 2002 a SCF for the GHARCOF region for the March–May period as part of its routine forecasting activities (URL: http://iri.columbia.edu/climate/forecast/sup/Feb02_Afr/map.html).

The outlook was the highest likelihood (40% probability) of normal conditions, a good chance of higher-than-average rainfall (35% probability) with a lower chance (25% probability) of drier conditions. This forecast was erroneous as exceptional rainfall was experienced across the western Kenyan highlands in late April and early May 2002 [4] (see below). We considered that the level of accuracy demonstrated by this SCF, coupled with the limited quality of information provided (probability estimates in three terciles) and the low temporal and spatial specificity compromised their usefulness for this emergency. Though not helpful in the short-term, SCFs should be reconsidered if their accuracy and information content is demonstrated to improve markedly in the future.

Early warning

Rainfall estimate (RFE) data for Africa are routinely available in near real-time from the Africa Data Dissemination Service (ADDS) [23] (<http://edcsnw4.cr.usgs.gov/adds/>). Satellite and meteorological station data are combined [24] to provide a continent-wide digital coverage of RFEs at an 8×8 km spatial resolution and are presented as rainfall totals (mm) per dekad. The first dekad for a month is the total of rainfall in days 1–10, the second in days 11–20 and the third in days 21–28, 29, 30 or 31, depending on the length of the month. Each new dekad is available on-line approximately one day after it has past, and an archive is available from the second dekad of July 1995. We retrieved the RFE data for the duration of the archive and extracted district total RFEs for all ‘epidemic prone’ highland districts (Fig. 1).

Dekadal RFEs for Kisii Central, Gucha, Nandi and Kericho (Fig. 2) show that during 1995–2001, average rainfall patterns were consistent with the notion of a bimodal rainfall with ‘long rains’ from March to May, and ‘short rains’ from October to December [18,25]. In Kisii Central and Gucha, through late April and particularly early May, rainfall totals were in excess of normal, but the RFEs for the months of April and June were not very different from average (Table 1) suggesting a seasonal malaria increase of normal proportions. By

contrast Nandi and Kericho received over a third more rain than is usual in May (Table 1), indicating that enhanced seasonal increases or epidemics were probable. The biggest anomalies occurred in the northern districts of the western highlands that we were unable to visit for logistical reasons (West Pokot, Trans Nzoia, Marakwet had 482, 413 and 298% of normal rainfall, respectively [4]) and the full extent of the emergency in these districts will only be known when surveillance data are collated retrospectively. Moreover, in the months of June and July, rainfall was significantly less than normal (Table 1) so that, in all four districts, cumulative total rainfall for August was close to average (Fig. 2). It was expected therefore that the June-July malaria increases and epidemics would wane following the normal seasonal pattern of disease in the region, since rainfall had decreased and lower temperatures from July to December restrict the development of the malaria parasite in the anopheline vectors. District-specific monitoring of rainfall, therefore, has the potential to give approximately four weeks notice of possible emergency conditions.

Early detection

During August 2002, we visited District Health Management Teams (DHMT) in Kisii Central, Gucha, Nandi and Kericho districts to collect information on district total malaria out-patient (OP) attendance until the end of August 2002 and during the preceding five years. In addition in each district data from four health facilities (in-patients and OP) were collected to compare with district totals. The patterns revealed at the facility level largely corroborated those at the district level (see reference [4]).

The WHO quartile [14], Cullen [26] and cumulative sum (C-SUM) [27–29] epidemic detection techniques have been proposed as useful for promoting epidemic preparedness using surveillance data and were therefore implemented on the district malaria OP data. These three epidemic detection techniques use five years of retrospective monthly case data to determine an average or base year. The WHO method triggers an alert when current cases exceed the upper 3rd quartile or the ‘upper normal limit’ [2,14]. The Cullen method [26] alerts when cases exceed the mean plus two times the standard deviation for a given month. The C-SUM uses the same approach, but determines the base year and threshold using observations from the present month and the previous and following months [27–29].

Surveillance activities experienced severe logistical constraints in each of the four districts visited and capacity to fulfil statutory requirements [30] was weak. The recently initiated WHO system for Integrated Disease Surveillance and Response (IDSR) was not obviously active during the current emergency. Despite these constraints, however, total OP data for all districts were locally available and collected during field visits [4].

Figure 3 shows seasonal increases to have occurred in Kisii Central and Gucha and true epidemics in Nandi and Kericho. The temporal resolution of monthly reporting of OP admissions was not sufficient for the early detection of epidemics (none of the techniques indicated unusual conditions in May) but was useful for objective quantification of the scale of the emergency. Weekly reporting from May to July would increase the temporal sensitivity of early detection. Though a rigorous modelling exercise is needed to evaluate which epidemic detection technique is preferable in seasonal mesoendemic environments [31], the C-SUM method performs well because of its relative insensitivity to inter-annual shifts in the timing of disease burden.

MEWS policy considerations

Normal rainfall conditions in Kisii Central and Gucha led to typical seasonal malaria increases in these districts while exceptional May rainfall in Nandi and Kericho led to true malaria epidemics during June and July of 2002. These conditions gradually and naturally

abated during August. Although the seasonal forecast was misleading, early warning through RFE data was potentially extremely valuable in its timeliness and spatial and temporal accuracy. 'Early detection' (surveillance) of malaria OP, as a result of data being collected and analyzed on a monthly basis, provided sentinel information too late to allow the control community to mount a timely response. The RFE data provided a warning four weeks ahead of the malaria upsurge. In addition, RFE data are free, geographically comprehensive, provided in near real-time and require minimal training and technical facilities to use.

Epidemic forecasting, detection and control is currently the responsibility of the Provincial and District Outbreak Management Teams within the Disease Outbreaks Management Unit (DOMU) of the Ministry of Health, in partnership with non-governmental organizations. The National Malaria Strategy 2001–2010 includes provision for a 20% national buffer stock of sulfadoxine–pyrimethamine (SP) antimalarials, but equipment and supplies for indoor residual spraying are not included, and individual districts have responsibility for raising funds to support this intervention. Given the utility of RFE data, a central level focus on early warning would probably represent an effective investment for epidemic preparedness. Sensitization of health staff at district level to the seasonal nature and epidemiological pattern of malaria in the highlands, and the need for vigilance in the weeks leading up to the rainy season would contribute to better planning for and the management of predictable seasonal resurgence. These objectives may also be assisted by proposed high-resolution malaria seasonality maps [15,32,33], which is an area of on-going research.

DHMTs need to identify and provide evidence for exceptional seasonal epidemics to mobilise additional resources held centrally. Typically, human resources at district and national levels for surveillance are stretched, but developing central capacity for early warning in combination with strengthening routine district level surveillance would be an appropriate investment of time and effort. Current integrated disease surveillance systems and routine health information and management systems are weak and failed to provide timely information during the 2002 epidemic. This generic support to HMIS would, in the short term, increase the appreciation of the seasonal nature of transmission and in the longer-term may help facilitate a movement to weekly data collection if the benefits of surveillance can be seen. Considerable efforts are underway by the DoMC in collaboration with the highland malaria project (HIMAL) to test more extensively these new systems for the prediction and detection of malaria epidemic in the East African highlands (<http://www.himal.uk.net>).

Are the highlands a special case?

The highlands are typical of the rest Kenya, with poor access to and use of insecticide-treated bednets (ITNs) (only 5.3% of the population of Kisii central and Gucha sleep under nets), emerging antimalarial drug resistance despite only 2% late treatment failure for SP and amodiaquine (AQ) being documented in Nandi in June 2001 (<http://www.eanmat.org>), antimalarial products frequently used by the community from the informal sector failing internationally acceptable quality assurance standards (40% of SP and AQ branded products failed during tests undertaken in 2002 (A. Amin, pers. comm.)), poor informal and formal case management (in Kisii Central and Gucha less than 5% of febrile children access SP within 24 h of disease onset [34]), and inadequate prescription practices by formal health service providers. This combination of problems means that communities living with poorly developed functional immunity to infection may serve as sensitive sentinels for the effectiveness of the national malaria control strategy.

We would, however, argue that emphasis should be given to improved planning cognisant of the seasonal epidemiology of risk, given that every year ~25% of the annual case burden is

in June and July [25]. This should concentrate central, provincial and particularly district level efforts at preparedness [indoor residual spraying (IRS), ITN purchase and re-treatment advocacy, community mobilisation and education, drug stock/efficacy/resistance audits, medical staff audits, retraining *etc.*] in the months of April and May before the predictable seasonal resurgence in June and July. Further considerations for the highlands might include a shift in emphasis within district plans for malaria control to allow for: (1) more advocacy for the introduction of IRS, which evidence shows to be a cost-effective intervention in highland districts [35,36]; (2) routine suspension of cost sharing for malaria treatment in May-July to encourage more prompt treatment of disease as a mid-way to mass drug administration (MDA), which historically, has been shown to be dramatically effective [8–10,37]; (3) the strict management of leave during the months of May, June and July for key medical and administrative staff at the relevant districts, provinces and central levels; and (4) embracing the rôle of the media as an efficient vehicle to disseminate public health information through appointing a press representative to assist the quality control of information reported.

While central early warning through rainfall monitoring has shown to have predictive skill, seasonal climate forecasting and monthly case surveillance were not informative. Improved management of the seasonal malaria in the highlands with or without MEWS would have a considerable impact on the delivery of healthcare in the region. Moreover, the evidence shows that the malaria situation in the highlands is not a special case that demands significant revisions to national malaria control policy. Increasing access to affordable, efficacious preventative and curative strategies are as relevant here as they are among the more intense transmission areas of Kenya.

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Fig. 1.

A map of the Kenyan Ministry of Health-defined epidemic-prone districts of the western highlands overlaid on a digital elevation model (a) with their location in Kenya (b). Note districts partitioned in the 1999 census from 'parent' districts classified as epidemic prone have also been included. The four visited districts are bordered in red. 1 West Pokot, 2 Trans Nzoia, 3 Marakwet, 4 Keiyo, 5 Uasin Gishu, 6 Lugari, 7 Kakamega, 8 Nandi, 9 Butere, 10 Vihiga, 11 Kericho, 12 Buret, 13 Kisii North (Nyamira), 14 Kisii Central, 15 Bomet, 16 Gucha, 17 Trans Mara.

Fig. 2.

Rainfall patterns in four epidemic prone highland districts of Kenya for Kisii Central (a-b), Gucha (c-d), Nandi (e-f) and Kericho (g-h). Figs 2a, c, e and g present dekad rainfall (yellow bars) for each district in 2002. The lower black line shows the district average for each dekad for the 1995–2001 period and the upper black line is this average plus 1.96 times the standard deviation. We should expect the upper black line to be exceeded in only one of 20 observations. A rainfall total above the lower line is therefore wetter than normal and above the upper line exceptionally so. These exceptionally wet dekads are emphasized with red bars in both graphs. Figs 2b, d, f and h plot the cumulative total for 2002 (bars) against the cumulative total rainfall for the average year (line). January to August 2002 inclusive were available at the time of writing. Rainfall data obtained from Africa Data Dissemination Service (<http://edcsnw4.cr.usgs.gov/adds/>), as described in Refs [4,23].

Fig. 3.

Epidemic detection for four epidemic prone highland districts of Kisii Central (a), Gucha (b), Nandi (c) and Kericho (d). The WHO, Cullen and C-SUM methods are presented for each of the Kisii Central, Gucha, Nandi and Kericho districts. In each graph the black bars are 2002 cases. If a bar exceeds the blue line it is a WHO defined epidemic, the black line a Cullen defined epidemic and the red line a C-SUM defined epidemic. Out-patient admissions data obtained from Ref. [4].

Table 1

Rainfall estimate data expressed as the proportion of the monthly average for 1995–2001 in Kenya^a

District	April	May	June
Kisii Central	7.0%	–7.3%	–38.6%
Gucha	1.0%	1.0%	–26.4%
Nandi	4.5%	37.0%	–40.5%
Kericho	–8.4%	40.6%	–32.1%

^aIn May, for example, Nandi and Kericho received 37 and 41 percent more rain than is normal for that month respectively. Negative numbers indicate less rainfall than normal. Rainfall data obtained from Africa Data Dissemination Service (<http://edcsnw4.cr.usgs.gov/adds/>), as described in Refs [4,23].